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(54) **Public key encryption with digital signature scheme**

(57)   An improved encryption and digital signature
method in accordance with the invention reuses an
encryption ephemeral key pair from an encryption proc-
ess in a digital signature process. The reuse of the
encryption ephemeral key pair in the digital signature
process advantageously results in reduced byte size of
the digital signature and reduction of costly computation
overhead. In a preferred embodiment, the invention is
based on the El Gamal encryption scheme and the
Nyberg-Rueppel signature scheme. The present inven-
tion is particularly useful for operation in conjunction
with small communication devices having limited
processing and storage, wherein such devices may
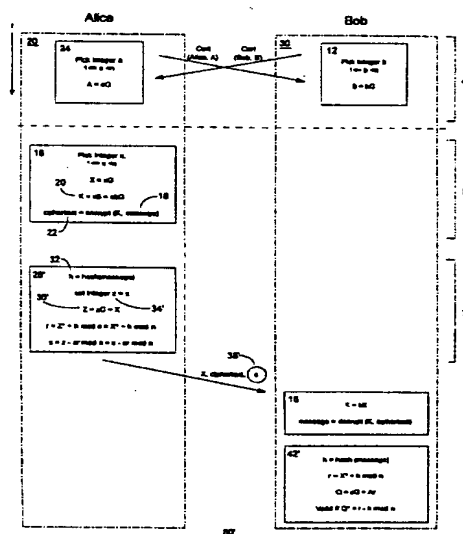communicate via bandwidth sensitive RF links.

FIG. 4 - PRIOR ART

Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001]   This invention relates to the field of public-key cryptography. More specifically, it is directed to a combined and improved public key encryption and digital signature scheme.

Background of the Invention

[0002]   Cryptography essentially provides confidentiality, authentication, integrity and non-repudiation for communication between different parties over public communication channels.

[0003]   In a public-key scheme, each user has a key pair consisting of a public key that is made publicly available, and a private key that is kept secret. The two keys are related by a hard one-way function, so as to make it infeasible to determine the private key from the public key. The public-key scheme allows a signature in the form of a digital signature to accompany a message.

[0004]   In the public-key environment, there are preferably three major processes. First, there is the certification process. A certificate authority creates a certificate that binds a user identity to the public key. A certificate repository provides a database of certificates where the public can access and retrieve the public key information of participants. In addition, there is a registration authority that acts as an assistant to the certificate authority. In essence, the registration authority is used to validate the binding. The second process is the encryption scheme that essentially converts a plaintext message into a ciphertext message. The third process is a digital signature process. The present invention relates specifically to the latter process and how it may be combined with the encryption process.

[0005]   A digital signature is a cryptographic primitive that provides a means for a user or an entity to bind its identity to a piece of information. A digital signature of a message is a sequence of bytes dependent on some secret known only to the signer, and, additionally, on the content of the message being signed. Such signatures must be verifiable, if a dispute arises as to whether a party signed a document. The process of signing entails transforming the message and a key unique to a particular user into a tag called a digital signature. A digital signature may be used to prove the identity of the sender and the integrity of data. To verify the digital signature, a recipient of a digitally signed message can use a verification rule associated with the digital signature scheme. Any attempt to modify the contents of the message or forge a signature will be detected when the signature is verified.

[0006]   Each of the above stages requires a certain degree of undesirable computational processing and a certain degree of byte-size overhead associated in the transmission of a communication to make the overall public-key process secure.

[0007]   Therefore, there remains an on going desire to reduce the additional byte and processing overhead associated with the public-key system while at the same time, not reducing the effectiveness of the public-key system.

SUMMARY OF THE INVENTION

[0008]   It is an object of the invention to reduce some of the drawbacks of the prior art public-key systems.

[0009]   It is an object of the invention to reduce computational processing associated with public-key schemes.

[0010]   It is an object of the invention to reduce byte-size overhead associated with the transmission of the digital signature.

[0011]   It is a further object of the present invention to provide a public key scheme with an improved encryption and digital signature scheme. The improved encryption and signature scheme can work in any finite cyclic group, such as a group of points on an elliptic curve over a finite field.

[0012]   More specifically, in the present invention, there is provided an improved encryption and digital signature scheme that reuses an ephemeral key pair from the encryption process in the signature process. Advantageously, the reuse of the ephemeral key allows the digital signature to be reduced in byte size. Another advantage is that costly computation may be avoided.

[0013]   According to the invention, a public-key encryption process comprises the steps of encrypting a plaintext message into a ciphertext message, the encrypting step includes the step of producing an ephemeral key pair, and signing a digital signature using the ephemeral key pair.

[0014]   A further aspect of the invention involves a software program on a computer-readable storage medium, which when executed by a processor performs a public-key encryption process comprising the steps of encrypting a plaintext message into a ciphertext message, the encrypting step includes the step of producing an ephemeral key pair, and signing a digital signature for the ciphertext message using the ephemeral key.

[0015]   In a preferred embodiment described herein, the invention is based on the El Gamal encryption and Nyberg-Rueppel signature schemes. Other encryption and digital signature schemes are all well within the scope of the invention.

[0016]   In the inventive process or software program, the ephemeral key pair may be produced by generating an encryption ephemeral private key x and calculating an encryption ephemeral public key $X = xG$, where G is a generator. According to a further preferred embodiment, the digital signature comprises a

first value r and a second value s, and the encryption ephemeral public key X, the ciphertext message and the second value s of the digital signature are transmitted from a sender to a receiver. At the receiver, the transmitted ciphertext message is decrypted, the first value r of the digital signature is calculated using the decrypted message and the transmitted encryption ephemeral public key X and the digital signature is validated based on the calculated first value r and the transmitted second value s.

[0017] With respect to the notation adopted herein and described below, the improved digital signature scheme uses the value of x, an encryption ephemeral key, for the value of z, a signature ephemeral key, instead of generating a random value for z, as in the prior art. Consequently, the transmitted digital signature of the present invention comprises a value s. A value of r, which according to conventional methods must be transmitted with the message, is instead reconstructed on the recipient end based on given values in the sender's transmission. In this improved scheme the overall combined El Gamal encryption scheme and the Nyberg-Rueppel digital signature scheme is optimized for faster computation time and lower overhead bandwidth. In particular, the computation of $Z = zG$ is avoided by the sender in the digital signature stage and the byte-size overhead associated with the digital signature transmission is reduced.

[0018] The present invention is preferably configured to operate in conjunction with small devices having limited processing and storage such as those disclosed in co-pending Canadian Patent Application No. 2,276,697, filed on June 28, 1999, laid-open on Dec. 29, 1999 and titled "Hand-Held Electronic Device With a Keyboard Optimized for Use With The Thumbs". Other systems and devices in which the invention may be implemented include, but are not limited to, wireless communication systems, wireless hand-held communication devices, personal digital assistants (PDAs), cellular phones and two-way pagers.

[0019] The present invention addresses specific dilemmas faced in electronic communication devices that are both bandwidth and computation load sensitive.

[0020] Further features of the invention will be described or will become apparent in the course of the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] In order that the invention may be more clearly understood, the preferred embodiment thereof will now be described in detail by way of example, with reference to the accompanying drawings, in which:

Fig. 1 is a functional diagram of a prior art El Gamal public-key encryption scheme;
Fig. 2 is a functional diagram of a prior art Nyberg-Rueppel digital signatures scheme;

Fig. 3 is a functional diagram of a prior art public-key system combining the schemes illustrated in Figs. 1 and 2;
Fig. 4 is a functional diagram of the present invention's public-key system with an improved digital signature scheme; and
Fig. 5 is a block diagram of a communication system in which the invention could be implemented.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Notation Explanation

[0022] For clarity of the detailed description, the notation used herein is now defined. In the improved encryption and digital signature scheme to be described, any finite cyclic group, such as the group of points on an elliptic curve over a finite field is suitable for its application. In the preferred embodiment described herein, the present invention is based on combining the El Gamal encryption scheme and the Nyberg-Rueppel digital signature scheme. Other encryption and digital signature schemes are all well within the scope of the invention.

[0023] Upper case letters, such as A, B, G, K, Q, X Z, denote group elements. An upper case G throughout this description is a generator of the group and has order n. Lower case letters, such as a, b, h, r, s, x, z, denote integers modulo (mod) n. An upper case letter with an asterisk, such as. Z^*, denotes the conversion of a corresponding group element, i.e. Z, to an integer. For elliptic curves, $Z = (x,y)$ and Z^* is usually derived from the x of Z. The group operation is denoted by '+' and $aA = A + A + ... + A$, a times. In addition, $ciphertext = encrypt\,(K, message)$ denotes a symmetric key encryption function that encrypts a plaintext message using a key derived from a group element K and returns the corresponding ciphertext. Likewise, $message = decrypt\,(K, ciphertext)$ denotes a symmetric key decryption function that decrypts a ciphertext using a key derived from a group element K and returns the corresponding plaintext message. Finally, $h = hash\,(message)$ denotes a cryptographically secure hash function that hashes a message to an integer modulo n.

[0024] The detailed description now follows with reference to Figs. 1-5. In the functional diagrams of Figs. 1-4, time is represented as increasing from the top to the bottom of the diagrams, as indicated by the "t" arrow at the top of each diagram.

[0025] Fig. 1 is a schematic of the prior art El Gamal public key encryption scheme 10. An encrypted message exchange between a notional sender, Alice 20, and a notional recipient, Bob 30 is illustrated therein. In a certification stage 40, Bob randomly generates private key b and computes public key $B = bG$, as shown at 12. For the purposes of this description, it is assumed that Alice has Bob's authentic public key B. A certification

authority, if used, validates a public key by creating and issuing a certificate. Alice may receive Bob's certificate 14 directly from Bob, or from a publicly accessible public key repository. Alice verifies that the signature on the certificate is correct, and that the certificate has not expired or been revoked. If those conditions are satisfied, then the public key B in the certificate 14 may be trusted.

[0026]   In the illustrated encryption process 10, the sender Alice performs the processing indicated in block 16. A random integer x, known as an encryption ephemeral private key is generated and an encryption ephemeral public key $X = xG$ is calculated. X and x comprise an encryption ephemeral key pair. Alice then generates a secret encryption key $K = xB = xbG$ and encrypts her plaintext message 18 with secret key K 20. The encryption ephemeral public key X and ciphertext message 22 are then transmitted to Bob. Bob then calculates secret key $K = bX = bxG = xbG = xB$ and decrypts the ciphertext 22 back into plaintext message 18. This key agreement scheme is a protocol by which a pair of users, communicating over an insecure channel, may independently calculate the same secret key from publicly communicated values.

[0027]   Fig. 2 is a schematic of the prior art Nyberg-Rueppel digital signature scheme 60. In this scheme, Alice randomly generates private key a and computes public key $A = aG$ (see block 24). Similar to the scheme of Fig. 1, it is assumed that Bob has obtained Alice's authentic public key either directly from Alice or through a certificate 26 from a certification authority or public key repository. As shown in Fig. 2, a hash value h 32 is created from the message using a hash function. An ephemeral signature key pair (Z, z) is produced by randomly generating ephemeral signature private key z 34 and calculating ephemeral public key Z 36, where $Z = zG$. The digital signature 38, comprising values $r = Z^* + h \bmod n$ and $s = z - ar \bmod n$, are calculated and transmitted with message 18 to Bob.

[0028]   This scheme requires the message 18 as input into the signature and verification algorithms 42. The verification portion of the scheme verifies a signature with Alice's public key A, given the digital signature 38 comprising integers r, s and the message 18. The recipient verifies the message by creating the hash value h 32 using the same hash function and processing it with Alice's public key. The verification output is compared with the received signature r, s to determine its validity, as shown in block 42.

[0029]   Fig. 3 is illustrative of a traditional prior art public key encryption scheme using the El Gamal public key encryption scheme and the Nyberg Rueppel digital signature scheme. In this scheme 80, there are three main stages to a public key encryption scheme. First, there is a preliminary certification scheme 40, during which Alice and Bob obtain each other's authentic public key A and B. Second, there is an encryption process 50. Third, there is a digital signature scheme 70. As the

El Gamal and Nyberg-Rueppel schemes have been described separately above, a detailed description of the combined encryption/signature scheme in Fig. 3 will not be pursued. However, it is highlighted that the signature ephemeral private key z 34 is randomly generated by the sender, the signature ephemeral public key Z 36 is computed by the sender and the transmitted digital signature 38 comprises the integers r and s. The values of r and s representing the transmitted digital signature 38 are transmitted with the encryption public key X and the ciphertext in the prior art.

[0030]   There are, however, some undesirable characteristics associated with this prior art approach. Firstly, computational resources and time are consumed where Z is calculated with large bit numbers. Secondly, the byte-size overhead associated with the public-key transmitted information is undesirably large for bandwidth sensitive devices such as wireless communication devices. The present invention addresses these two undesirable qualities.

[0031]   Fig. 4 illustrates an overview of a preferred embodiment of the present invention. Like the prior art, there are three main stages to the preferred embodiment of the present invention, namely the certification 40', encryption 50' and digital signature 70' stage.

[0032]   In the certification stage, Alice generates a long term random private key a and computes public key A, where $A = aG$. Likewise, Bob randomly generates private key b and computes public key B, where $B = bG$. As described above in relation to Figs. 1-3, Alice and Bob exchange authentic public keys A and B directly, through a certification authority or through a public key repository

[0033]   In the encryption stage 40', Alice generates an encryption ephemeral private key as random integer value x and computes a corresponding encryption ephemeral public key X, where $X = xG$. As described above, the set (X, x) represents the ephemeral key pair produced in the encryption scheme. With this information, Alice uses Bob's public key B to compute secret key K 20, given by $K = xB$. Alice then encrypts the message producing $ciphertext = encrypt$ (K, $message$) 22.

[0034]   The present invention outlined in Fig. 4 deviates from the prior art scheme of Fig. 3 in several important aspects. The improved digital signature scheme of the present invention uses the encryption ephemeral key pair (X, x) produced in the encryption stage 50' as a substitute for the signature ephemeral key pair (Z, z) required in the digital signature stage 70'. The value of signature ephemeral private key z 34' is set to the value of encryption ephemeral private key x from the encryption stage. Consequently, the random generation of z and the computation of Z 36' are not required since signature ephemeral public key Z 36' equals encryption ephemeral public key X 20. Advantageously, this reduces the computational load on the sender. In essence, the value for x is used for two different pur-

poses. In the first instance, x is used for the encryption process scheme 50'. In the second instance, the x is also used in the digital signature scheme 70'.

[0035] After transmission of the encryption public key X 20, ciphertext 22 and signature s 38', Bob may then calculate secret key $K = bX$ and then decrypt the message by $message = decrypt (K, ciphertext)$. The digital signature scheme then preferably hashes the message 40 to calculate h, as indicated in block 42'. Two pieces of information for the digital signature still need to be computed, namely integers r and s. The integers are calculated as follows: $r = Z^* + h\ mod\ n = X^* + h\ mod\ n$ and $s = z - ar\ mod\ n = x - ar\ mod\ n$. However, only s in addition to the encryption ephemeral public key X and the ciphertext must be transmitted to Bob in the inventive scheme 80'. Rather than r being transmitted to Bob, r is instead reconstructed at the receive side by calculating $r = X^* + h\ mod\ n$. In this manner, the overall byte-size overhead associated with the digital signature 38' is reduced by not transmitting r. In a specific embodiment of the invention, the saving was in the range of twenty-two bytes. In portable two-way wireless communication devices, reducing the transmission by twenty-two bytes is considerably useful and advantageous.

[0036] The inventive encryption and signature scheme outlined in Fig. 4 would preferably be implemented in software in a communication system. The block diagram in Fig. 5 represents one such system 100 in which the inventive scheme could be used. In Fig. 5, 110, 112 and 114 are communication devices and 116 is certification authority or public key repository. In order for the devices to communicate using the inventive scheme, each device must first exchange authentic public keys with the other device or devices with which communication is desired. As shown in Figure 5 and described above, each device may communicate with a certification authority or public key repository 116 or with each other to accomplish public key exchange. Each communication device may incorporate software or hardware to perform the inventive encryption and signature scheme. Communication devices 110, 112 and 114 may be wired or wireless communication devices. This invention has particular application in, but not limited to, Personal Digital Assistants, mobile communication devices, cellular phones, two-way pagers and wireless two-way e-mail communication devices. One such illustrative device that may implement the present invention is disclosed in co-pending Canadian Patent Application No. 2,276,697, referenced above. In an alternative embodiment of the present invention, such a system as disclosed in Figure 2 of PCT/CA99/00494, filed on May 28, 1999, published on Dec. 9, 1999 as WO 99/63709 and titled "System and Method for Pushing Information From a Host System to Mobile Data Communication Device" may implement the present invention. In all such systems, a typical system for which the present invention is particularly useful is a low band-

width system such as one that utilizes an RF link in the communication path. The system and method of pushing information from a host system to a mobile described in the latter application is only one preferred system and method for the present invention herein; however, it is to be understood other types of systems and methods could be implemented that utilizes the present invention.

[0037] It will be appreciated that the above description relates to a preferred embodiment by way of example only. Many variations on the invention will be obvious to those knowledgeable in the field, and such obvious variations are within the scope of the invention as described and claimed, whether or not expressly described. For instance, the aforementioned process could obviously be extended to include multiple recipients from a single sender.

Claims

1. A public-key encryption process comprising the steps of:

   a) encrypting a plaintext message into a ciphertext message, the encrypting step includes the step of producing an ephemeral key pair; and
   b) signing a digital signature using the ephemeral key pair.

2. A public-key encryption process according to claim 1, wherein the encrypting step uses an El Gamal encryption scheme.

3. A public-key encryption process according to claim 1, wherein the step of signing a digital signature comprises generating the digital signature using a Nyberg-Rueppel digital signature scheme.

4. A public-key encryption process according to claim 1, wherein the step of producing the ephemeral key pair comprises the steps of generating an encryption ephemeral private key x and calculating an encryption ephemeral public key $X = xG$, where G is a generator.

5. A public-key encryption process according to claim 1, for encrypting messages for communication between a sender and a receiver, the process further comprising the steps of,
   at the sender,

   a) generating a sender private key a; and
   b) calculating a sender public key $A = aG$, where G is a generator,

   and at the receiver,

a) generating a receiver private key b; and

b) calculating a receiver public key $B = bG$, wherein the sender obtains an authentic copy of the receiver public key B and the receiver obtains an authentic copy of the sender public key A.

6. A public-key encryption process according to claim 5, wherein the step of producing the ephemeral key pair comprises the steps of generating an encryption ephemeral private key x and calculating an encryption ephemeral public key $X = xG$.

7. A public-key encryption process according to claim 6, further comprising the steps of, at the sender, generating a secret key $K = xB$ and encrypting a plaintext message using the secret key K to generate a ciphertext message.

8. A public-key encryption process according to claim 7, further comprising the steps of, at the sender, using the encryption private key x as a signature ephemeral private key and using the encryption ephemeral public key X as a signature ephemeral public key to generate a digital signature.

9. A public-key encryption process according to claim 8, wherein the digital signature comprises a first value r and a second value s, the process further comprising the step of, at the sender, transmitting the encryption ephemeral public key X, the ciphertext message and the second value s of the digital signature to the receiver.

10. A public-key encryption process according to claim 9, further comprising the steps of, at the receiver, generating the secret key $K = bX = bxG = xbG = xB$, decrypting the transmitted ciphertext message using the generated secret key K, calculating the first value r of the digital signature using the decrypted message and the transmitted encryption ephemeral public key X and validating the digital signature based on the calculated first value r and the transmitted second value s.

11. A public-key encryption process according to claim 1, implemented in a wireless communication system.

12. A public-key encryption process according to claim 1, implemented in a wireless hand-held communication device.

13. A public-key encryption process according to claim 1, implemented in a personal digital assistant.

14. A public-key encryption process according to claim

1, implemented in a cellular phone.

15. A public-key encryption process according to claim 1, implemented in a two-way pager.

16. A software program on a computer-readable storage medium, which when executed by a processor performs a public-key encryption process comprising the steps of:

a) encrypting a plaintext message into a ciphertext message, the encrypting step includes the step of producing an ephemeral key pair; and

b) signing a digital signature for the ciphertext message using the ephemeral key.

17. A software program according to claim 16, wherein the encrypting step uses an El Gamal encryption scheme.

18. A software program according to claim 16, wherein the step of signing a digital signature comprises generating the digital signature using a Nyberg-Rueppel digital signature scheme.

19. A software program according to claim 16, wherein the step of producing the ephemeral key pair comprises the steps of generating an encryption ephemeral private key x and calculating an encryption ephemeral public key $X = xG$, where G is a generator.

20. A software program according to claim 16, for encrypting messages for communication between a sender and a receiver, the software program performing the further steps of,
at the sender,

a) generating a sender private key a; and

b) calculating a sender public key $A = aG$, where G is a generator,

and at the receiver,

a) generating a receiver private key b; and

b) calculating a receiver public key $B = bG$, wherein the sender obtains an authentic copy of the receiver public key B and the receiver obtains an authentic copy of the sender public key A.

21. A software program according to claim 20, wherein the step of producing the ephemeral key pair comprises the steps of generating an encryption ephemeral private key x and calculating an encryption ephemeral public key $X = xG$.

22. A software program according to claim 21, wherein the software program performs the further steps of, at the sender, generating a secret key $K = xB$ and encrypting a plaintext message using the secret key K to generate a ciphertext message.

5

23. A software program according to claim 22, wherein the software program performs the further steps of, at the sender, using the encryption private key x as a signature ephemeral private key and using the *10* encryption ephemeral public key X as a signature ephemeral public key to generate a digital signature.

24. A software program according to claim 23, wherein *15* the digital signature comprises a first value r and a second value s, the software program performing the further step of, at the sender, transmitting the encryption ephemeral public key X, the ciphertext message and the second value s of the digital sig- *20* nature to the receiver.

25. A software program according to claim 24, the software program performing the steps of, at the receiver, generating the secret key *25* $K = bX = bxG = xbG = xB$, decrypting the transmitted ciphertext message using the generated secret key K, calculating the first value r of the digital signature using the decrypted message and the transmitted encryption ephemeral public key X and *30* validating the digital signature based on the calculated first value r and the transmitted second value s.

26. A software program according to claim 16, installed *35* in a wireless communication system.

27. A software program according to claim 16, installed in a wireless hand-held communication device.

40

28. A software program according to claim 16, installed in a personal digital assistant.

29. A software program according to claim 16, installed in a cellular phone. *45*

30. A software program according to claim 16, installed in a two-way pager.

50

55

Alice   Bob

FIG 1 – PRIOR ART

Alice   Bob

20

24

Pick integer a
1<= a <n

A = aG

26
Cert (Alice,
A)

40

32

28   h = hash(message)

36 pick integer z, 1<= z <n

Z = zG   34

r = Z* + h mod n

s = z - ar mod n

18   38

message, (r, s)

70

42   32

h = hash (message)

Q = sG + Ar
= (a-ar)G + Ar
= zG - arG + Ar
= zG - Ar + Ar
= Z

Valid if Q* = Z* = r - h mod n

60

FIG. 2 – PRIOR ART

Alice   Bob

t

20   24
            Pick integer a   Cert   Cert   30   12
            1<= a <n   (Alice, A) (Bob, B)   Pick integer b   40
                                                                            1<= b <n
            A = aG   B = bG

        16   Pick integer x,
                    1<= x <n
            20   X = xG   50
                      K = xB = xbG   18
            ciphertext = encrypt (K, message)
            22

            32
        28   h = hash(message)
            36 pick integer z, 1<= z <n
                    Z = zG   34   70
                    r = Z° + h mod n
                    s = z - ar mod n
                                            38
                                    X, ciphertext, (r, s)
                                                            16   K = bX

                                                            message = decrypt (K, ciphertext)

                                                            42   32
                                                                    h = hash (message)

                                                                    Q = sG + Ar

                                                                    Valid if Q° = r - h mod n

                                            80

10

FIG. 3 – PRIOR ART

Alice   **Bob**

<u>20</u>

24
Pick integer a $1 <= a < n$ $A = aG$

Cert   Cert
(Alice, A) (Bob, B)

<u>30</u>

12
Pick integer b $1 <= b < n$ $B = bG$

40'

16	Pick integer x, $1 <= x < n$
20	$X = xG$
18	$K = xB = xbG$
22	ciphertext = encrypt (K, message)

50'

32		
28'	$h = hash(message)$	
	set integer $z = x$	
36'	$Z = zG = X$	34'
	$r = Z^* + h \bmod n = X^* + h \bmod n$	
	$s = z - ar \bmod n = x - ar \bmod n$	

70'

38'

X, ciphertext, $\left(\,s\,\right)$

16	$K = bX$
message = decrypt (K, ciphertext)	

42'	$h = hash (message)$
	$r = X^* + h \bmod n$
	$Q = sG + Ar$
	Valid if $Q^* = r - h \bmod n$

<u>80'</u>
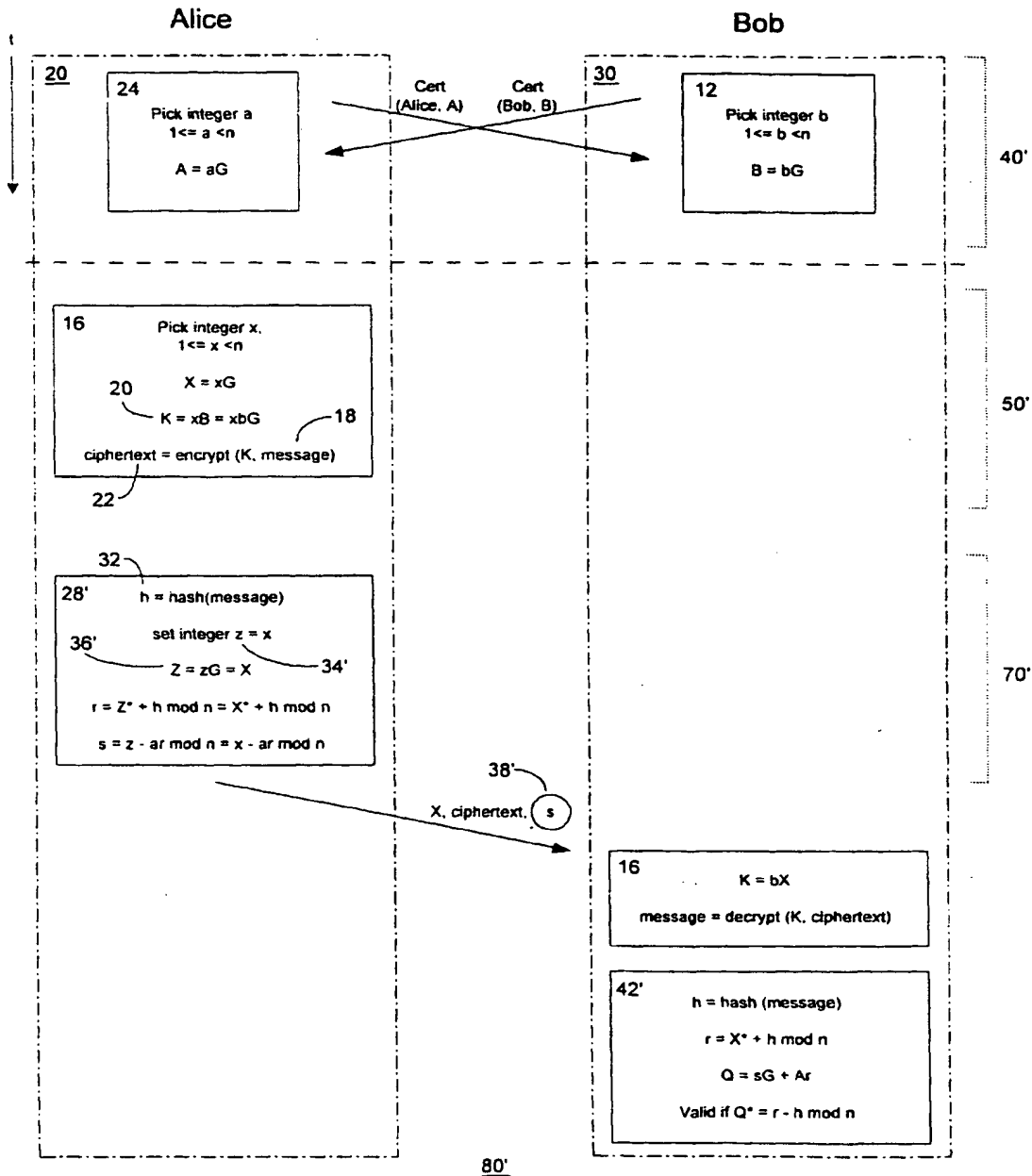
FIG. 4 - PRIOR ART

110

Communication
Devcice

116

Certification Authority
or
Public Key Repository

Communication
Device

112

Communication
Device

114

100

FIG. 5